MACMILLAN
Advanced
Research
Series

2

STRUCTURAL ANALYSIS OF HISTORICAL CONSTRUCTIONS

Possibilities of numerical and experimental techniques

Edited by

Paulo B. Lourenço

Pere Roca

Claudio Modena

Shailesh Agrawal

UPC

Structural Analysis of Historical Constructions, New Delhi 2006
P.B. Lourenço, P. Roca, C. Modena, S. Agrawal (Eds.)

Chemical Anchoring Systems for Strengthening and Structural Restoration Purposes

G. Ferrari
Italian National Research Concil, San Giuliano Milanese, Italy

ABSTRACT: The paper presents the experimental results of the evaluation of fitness for use of chemical anchoring systems used in the strengthening of historical masonry buildings. The research refers to a feasible operation of reconstruction of orientations to be performed within pre-existent vertical structures consisting of load-bearing masonry facings.

To properly frame the issue related to the fixing between masonry facings and floor elements of the reference model, the mechanical characteristics of the base materials constituting the system were determined beforehand having been determined in terms of compressive and extraction strength.

The evaluation of the results obtained from the materials used was followed by an experimentation with load tests on wall-floor connections realised with chemical anchors showing a good capacity of transferring loads assessed in terms of moment and absorbed shear. The obtained information allows to consider the restoration operations developed with the above technique as

1 INTRODUCTION

As far as the reuse and structural adjustment of historic masonry constructions are concerned: "one of the main issues to solve at consolidation stage is ensuring the actual collaboration between the new and existing structures in order to create a whole set of buildings able to withstand stresses"; this design requirement is usually met by widely and systematically adopting fixing systems that can make the different structural elements involved in the restoration project integral with one another.

The structural adjustment aimed at reusing historical masonry constructions, as described above, has been lately based on post-installed chemical anchoring systems more compatible than other available systems (mechanical fixing by means of anchor-bolts), with the resistance characteristics of base materials used during the different stages of recovery of pre-existent horizontal and vertical structures. Among the most interesting applications, a special mention goes to the insertion of new floors in pre-existent deckings. As far as this action is concerned, the structural issue consists in connecting the metal angle bars, acting as supporting elements to the warping of the new floor, to the masonry; the operational phases of the construction procedure include: realization of predetermined holes in the existing masonry, the successive injection of resin and the insertion of threaded bars on which to anchor the metal profiles acting as supports to the floors being reconstructed.

When fixing is made by means of base materials making up the masonries' vertical facings, the fitness for use of a specific chemical anchor, before final connection, can be ensured only by compulsorily running a set of tests aiming at extracting the bars in order to determine the ultimate tensile strength of the bar-anchor-masonry assembly.

To this end, the following pages will illustrate the first results obtained from the research and experimental activity performed on newly conceived and formulated chemical anchors (based on epoxy and urethane resins) used to strengthen and reuse historically valuable masonries whenever the available protection actions must generally satisfy both the need of collaboration between existing materials and basic elements, and the new structural functions that must be performed by each element in the different action typologies carried out.

2 CHARACTERISTICS OF MASONRY SAMPLES AND MECHANICAL PROPERTIES OF BASE MATERIALS

The study of the mechanical characteristics of the base materials and of the masonry samples plays a role of primary importance in the design of chemical anchors destined to the static restoration of old buildings. Only mechanical tests carried out on base materials and on masonry samples of large dimensions (including at least 4 – 5 mortar layers) could lead to a reliable appraisal of the main mechanical properties needed for the performance evaluation of anchors.

For this reason, wall panels with geometrical dimensions BxLxH of 12.0 x 52,0 x 48,0 cm, levelled on their upper and lower parts through the interposition of a layer of distribution and levelling mortar, have been prepared and grouped in three series of six elements each, in order to obtain a representative number of samples to carry out the tests envisaged for the steps of the experimentation.

The preliminary scopes of the survey envisage the experimental determination of the average ultimate tensile strength of the reference chemical anchoring (in the system consisting of the bar – resin (chemical anchoring) – masonry); the successive operational steps of the experimentation have therefore concerned the execution of compression break tests on the panels for what concerns the elements belonging to the first series and tests foreseeing the extraction of the fixing bar of the chemical anchoring placed either in the solid brick or in the mortar of the joints of the masonry making up the panels, for the second and third series of samples respectively.

As the panels were being made, also other specimens were prepared to determine the most meaningful mechanical characteristics of each individual constituent material of the wall facing by proceeding in accordance with the indications of standard UNI-EN 998-2.

The specimens mentioned above are, namely:

For mortar:

a total of 6 prismatic specimens with dimensions 40x40x160 mm; 3 specimens were prepared for each of the two mixes used to realize the panels; after having determined the mass, the specimens have been subjected to bending stress then to compressive stress on the 12 resulting half-parts; following the indications of standard UNI EN 196-1 the obtained values are as follows:

Apparent mass per unit volume (average value out of 6 specimens)	kg/m^3	1865
Average compressive strength after 28 days according to UNI-EN 196-1 (average value out of 12 specimens)	daN/cm^2	58,8

For brick tiles:

each of 8 solid bricks were cut in two half bricks and levelled on the faces xy of the laying planes, thus producing, by overlap through interposition of high-resistance mortar (f_{bk} = 52,5 N/mm^2) of the half blocks, 8 specimens with nominal dimensions 12x12x9,5 cm to be subjected to compressive test in direction Z in accordance with the Standards for the acceptance of brick-tile materials (Royal Decree R.D. 16/11/1939, n. 2233) at present in force in Italy; prior to loading tests cycles, the mass per unit volume was measured on all specimens. The experimental results are given below:

Mass per unit volume,	gr/cm^3	1,768
Average compressive strength (direction Z)	daN/cm^2	203,41

After the individual materials have been characterized, and before proceeding with the execution of extraction tests on the reference anchors inserted in the sample masonry panels, the elements belonging to the first series have been subjected to compressive break tests in order to define a limit value for the masonry that may be representative of the base material on which the anchors will be realized.

During this phase the panels belonging to the first series have been individually subjected to simple compressive test with a centred load generated by a 2000 KN press in order to determine their compressive break load; the obtained average value was 54600 daN which corresponds to an average compressive strength of the masonry of 87 daN/cm^2, as shown in the table below, containing the results obtained for each individual sample.

Table 1 : Results of simple compressive tests on panels

Sample abbreviation	Mass per unit volume (Kg/m^3)	Nominal reacting section (cm^2)	Load (daN)	Compressive strength daN/cm^2
I/A1	1586	624	34200	55
II/B4	1650	624	55000	88
III/C10	1656	624	57000	91
IV/C16	1671	624	65600	105
V/C17	1691	624	60000	96
VI/C18	1715	624	55800	89
Average Value	1661	624	54600	87

3 RESULTS OF EXTRATION TESTS

Failing a reference standard on chemical anchors and proceeding as provided for by Annex B of the EOTA Guide on metal anchors, the tests meant to determine the admitted and categorical conditions for using the sample chemical anchoring have been carried out on a typology of fixing element characterized by the same epoxy - urethane resin, the same threaded bar (8MA, steel class 5,6), the same positioning conditions evaluated in terms anchor laying depth (12 cm) and the same diameter of the hole made in the base material making up each wall panel used for the ongoing experimentation.

Having chosen these conditions for actually realizing the sample chemical anchoring, this results to be composed of a piece of M8 threaded bar (L = 500 mm) inserted into a 10 mm diameter hole made in the base material (brick-tile or mortar) all along the masonry thickness (the laying depth being equal to the masonry's head thickness, namely: 120 mm nominal, 116 mm actual thickness) after having filled the hole with resin; as illustrated (Figs. 1,2,3), the samples have been prepared in accordance with the instructions provided by the manufacturer, throughout the different preparation steps.

The realization of sample anchors of the two reference series, whose respective threaded bar insertion points are located at different positions (the bar being respectively inserted in the mortar between courses or in the mass of the wall's brick-tile), was followed by the extraction tests in order to experimentally determine the load-bearing capacity under tensile stress of the anchoring, assessed in terms of average ultimate tensile strength of the fixing element (bar) realized by means of epoxy - urethane resin inserted into the different insertion points of the individual masonry panels of each series characterized by a different prevailing base material; solid brick's burnt clay or cement mortar.

Extraction tests have been conducted by means of a load cell with dynamometric wrench (expressly conceived for these types of action) leaned against a conical spacer provided of two flanges with centring the threaded bar of the anchoring element in order to allow failure to take place according to a mode as similar as possible to the one that would occur to the anchoring element under real service conditions (Figs. 4,5,6).

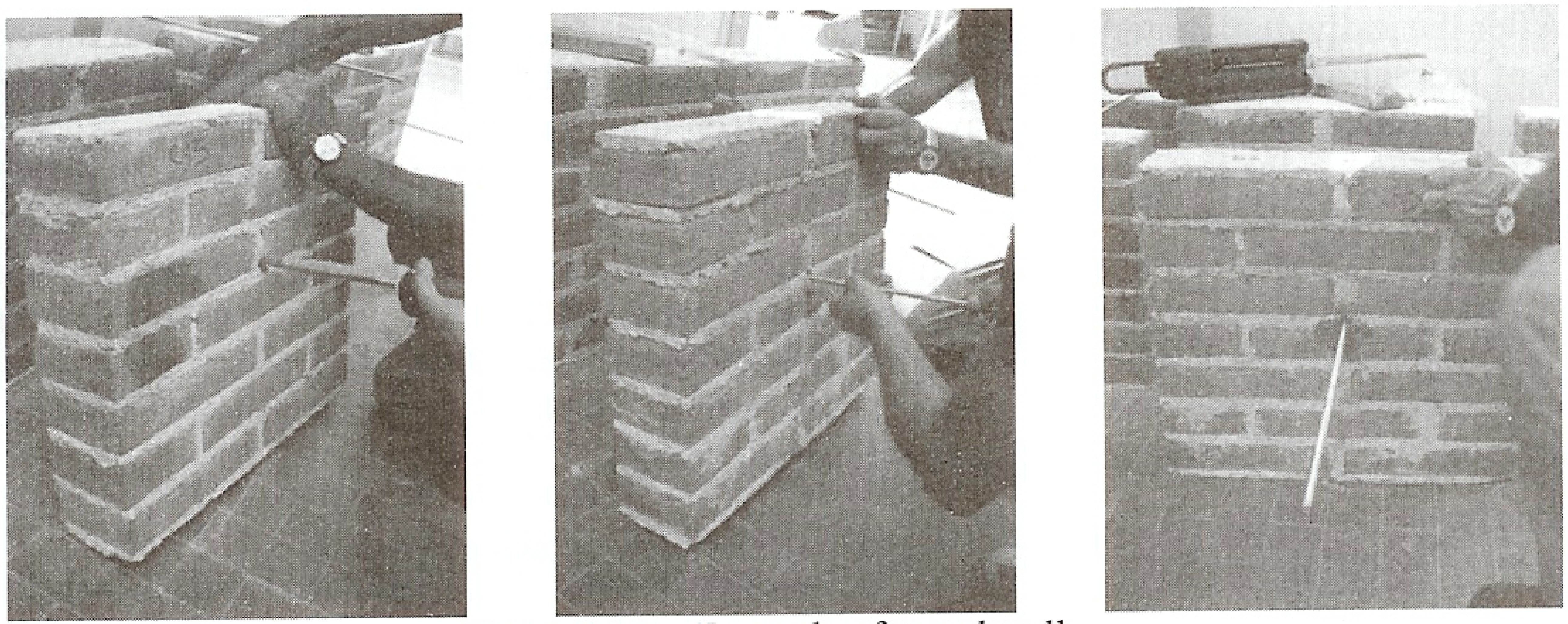


Figure 1,2,3 : Example of tested wall

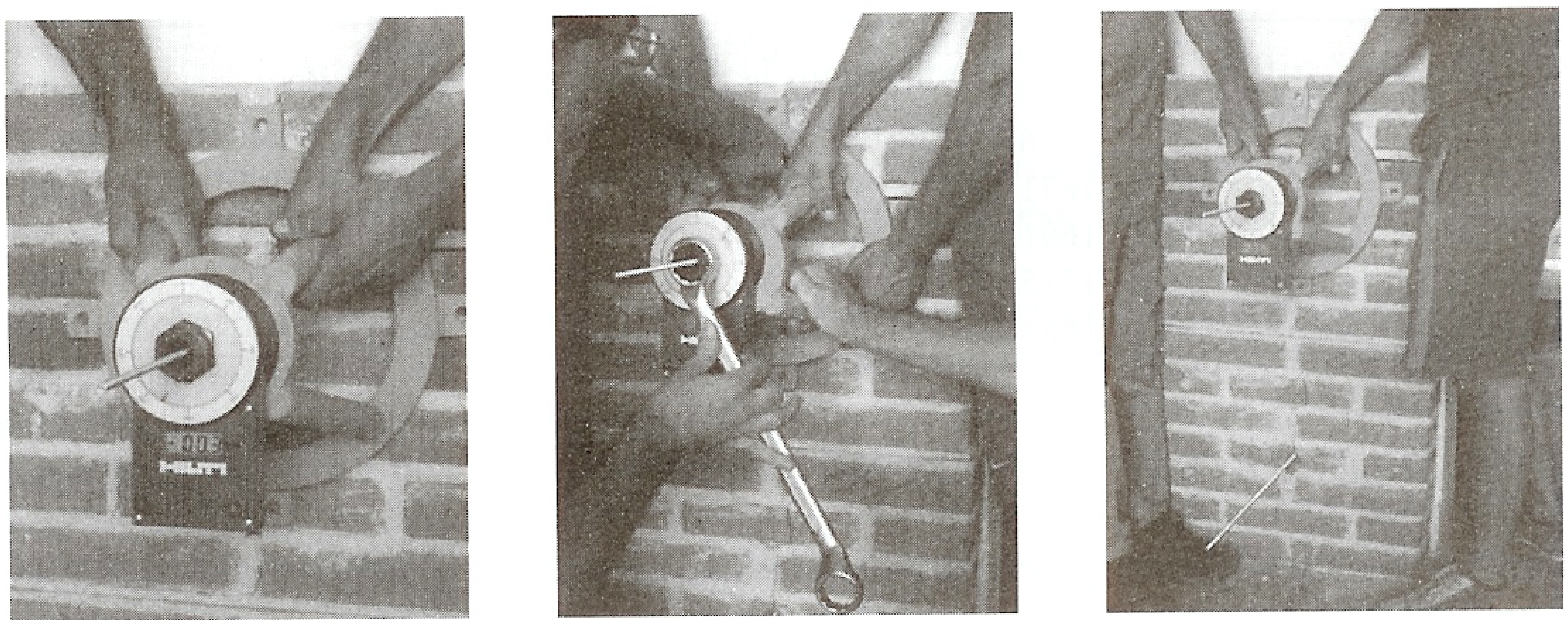


Figure 4,5,6 : Single phases of the extraction test

The results of the extraction tests performed on the second and third series of samples are contained in the tables 2 and 3: Table 2 shows the values of the extraction force obtained on individual samples and describes the failure modes observed on the base material of the fixing element consisting of only the burnt material of the solid brick, while Table 3 shows the values of the extraction force measured on masonry panels where the base material mostly concerned by the test is the cement mortar interposed between solid bricks courses.

By making a comparison among the various results obtained from the base materials investigated during extraction tests, it was possible to notice that the anchoring shows a greater tensile strength capacity when it develops exclusively on the burnt material of the masonry facing brick-tile.

4 RESULTS OF BENDING/SHEAR TESTS ON SAMPLES OF WALL-FLOOR CONNECTION REALIZED WITH CHEMICAL ANCHORS

To prove that the potential of use of chemical anchors made of epoxy- urethane resins and threaded bars can be actually applied to re-adjust deckings of historical buildings with load-bearing masonry, as a reversible solution with a low impact on existing structures,

Table 2 : Results of the extraction tests performed on masonry samples, series II – Base material: burnt clay

Panel abbreviation	Mass per unit volume (Kg/m3)	Extraction force (daN)	Notes and remarks
I/B7	1639	1310	Tensile strength failure of the wall without extraction of 8MA bar
II/C13	1671	1020	Tensile strength failure of the wall without extraction of 8MA bar
III/C14	1620	1410	Failure of 8MA threaded bar under tensile strength
IV/D3	1689	1620	Failure of 8MA threaded bar under tensile strength
V/D4	1603	440	Tensile strength failure of the burnt clay block
Average value	1644	1160	Average ultimate tensile strength of the anchoring

Table 3 : Results of the extraction tests performed on masonry samples, series III – Base material: mortar

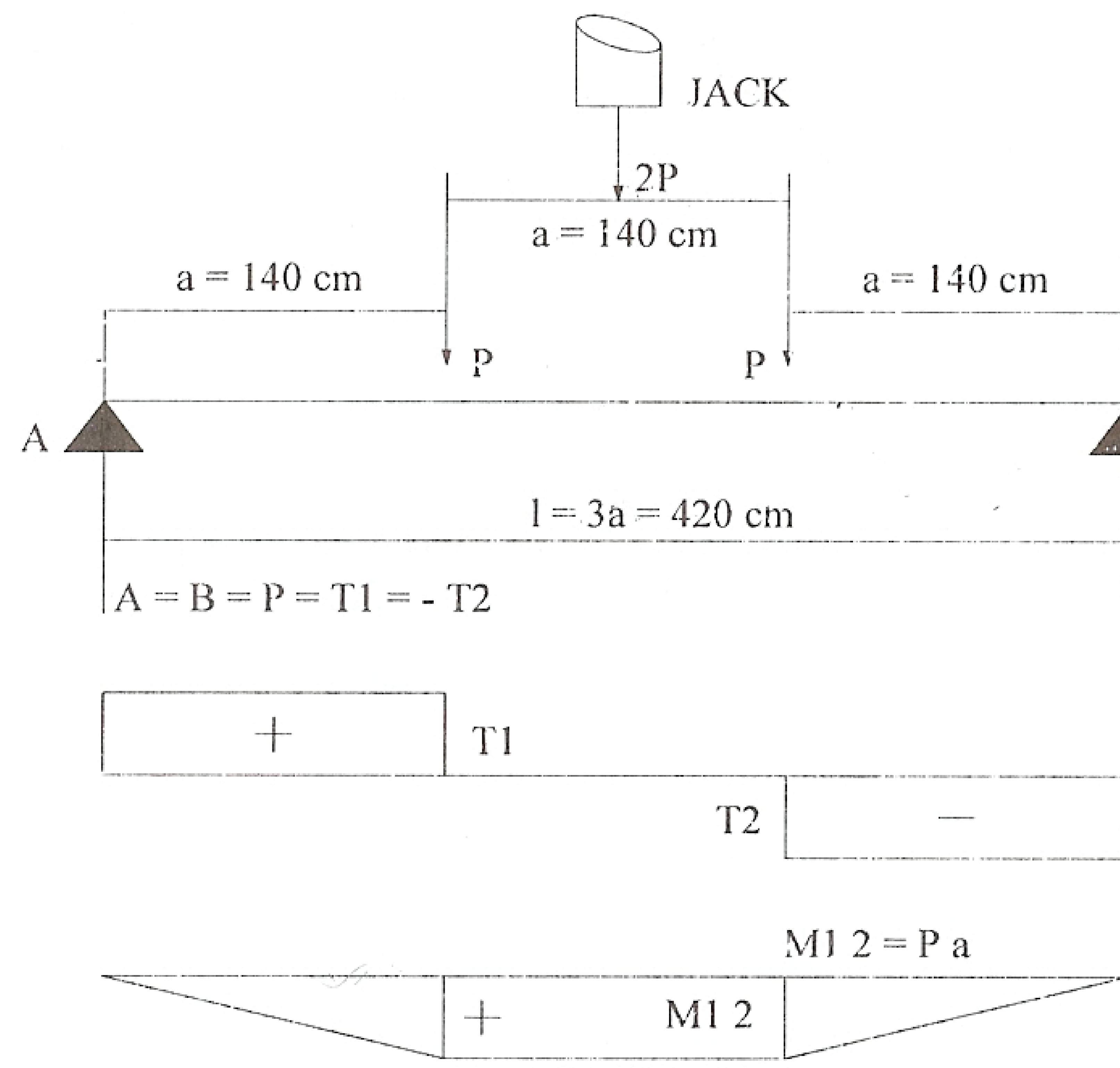
Panel abbreviation	Mass per unit volume (Kg/m3)	Extraction force (daN)	Notes and remarks
I/B8	1644	810	Tensile strength failure of the mortar with extraction of 8MA bar starting to occur
II/B9	1684	790	Tensile strength failure of the mortar without extraction of 8MA bar
III/C15	1628	760	Tensile strength failure of the mortar without extraction of 8MA bar
IV/D1	1585	650	Tensile strength failure of the mortar without extraction of 8MA bar
V/D2	1589	830	Tensile strength failure of the mortar without extraction of 8MA bar
Average value	1626	768	Average ultimate tensile strength of the anchoring

it was decided to perform bending-shear tests on floor latticed joists connected with the facings of the head masonry according to the scheme illustrated at Fig. 7, after preparation by resin and threaded rebar anchors of the upper reinforcing rod of the lattice work of the individual samples prepared for the experiment (8MA bar for two models, 10MA for one model).

The performed bending-shear tests involved the application of two equal loads at 140 cm from the supports (such a distance corresponding to one third of the 420 cm overall span obtained by positioning the individual latticed joists used for the experiment), in order to obtain a constant shear, with opposite signs, at the end sections of the joists and a constant moment along the central section delimited by the bar distributing the 2P force generated by the loading jack; the end anchors between the joist and the masonry of the fixing walls were realized at the supports.

The system connecting the latticed joist to the masonry head elements was realized by introducing the metal bars in the masonry elements The installation of the bars have allowed the subsequent positioning of the joist and the connection by overlap of the upper reinforcement of the joist's lattice with the protruding parts of the threaded bars acting as rebar anchors.

Afterwards, the threaded bars have been chemically anchored to the masonry with epoxy - urethane resin; subsequent to the envisaged setting time of the resin, the connection between vertical and horizontal elements was completed by casting the finishing concrete of the latticed joist.



$$f = \frac{Pa\,(3l^2\ \ 4a^2)}{24EJ} = \frac{Pa\,(23\,a^2)}{EJ}$$

Figure 7 : Load scheme of tests on samples

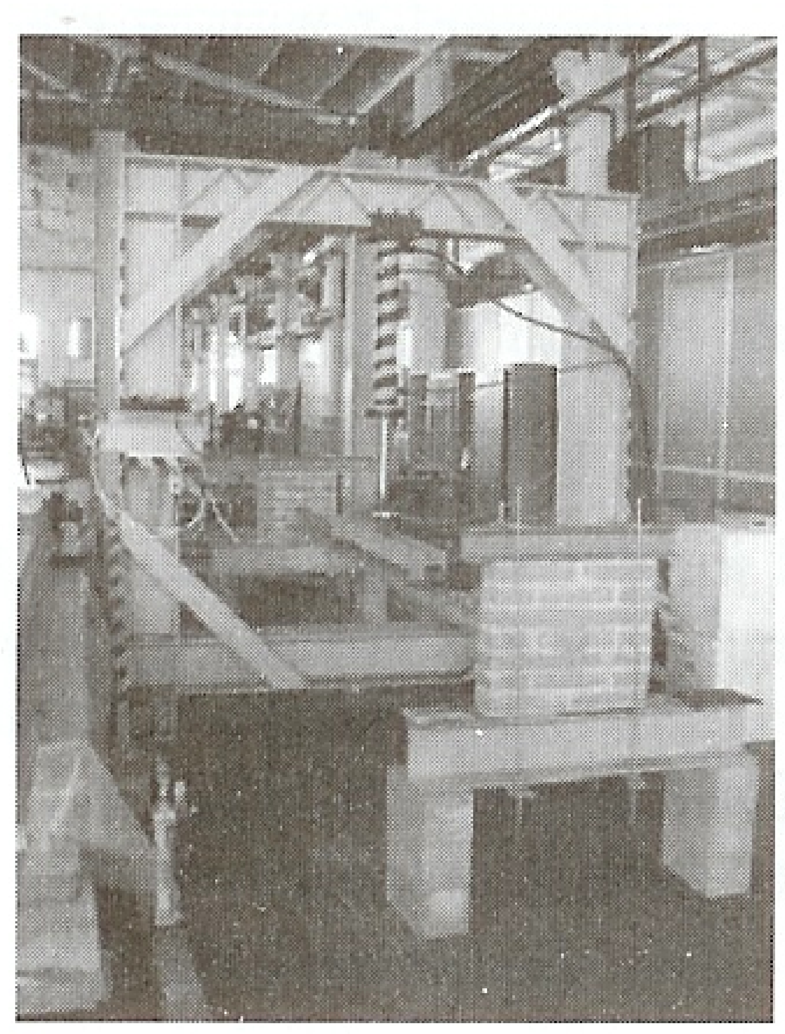
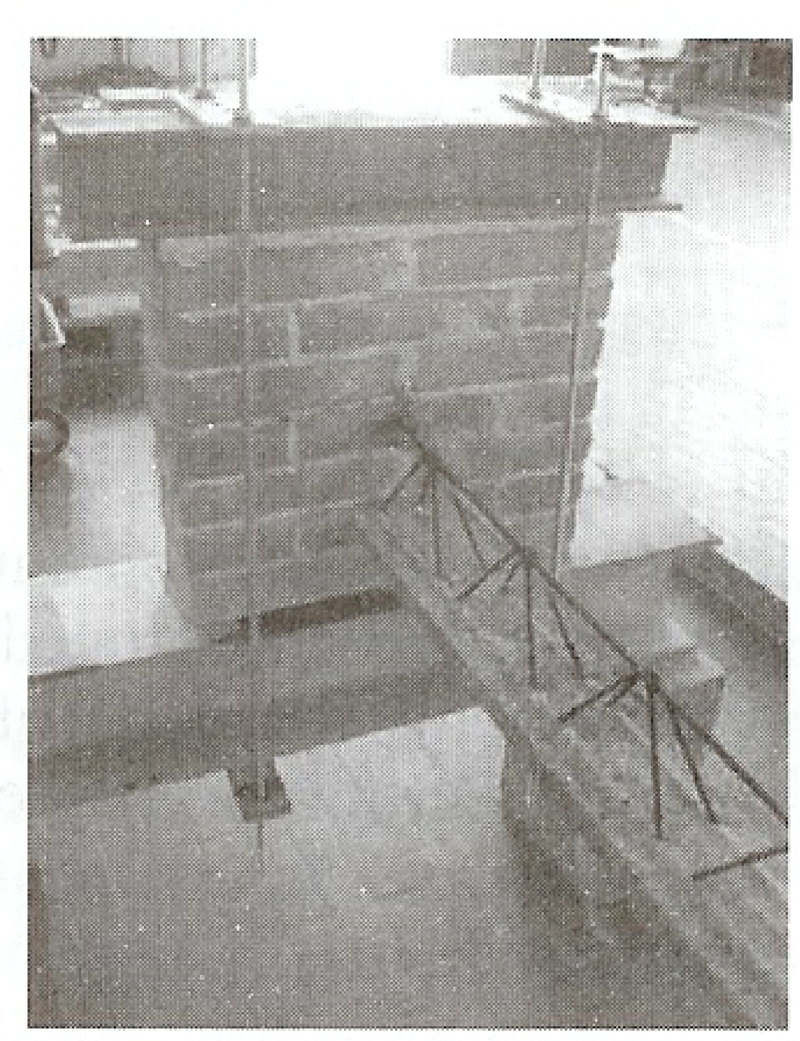
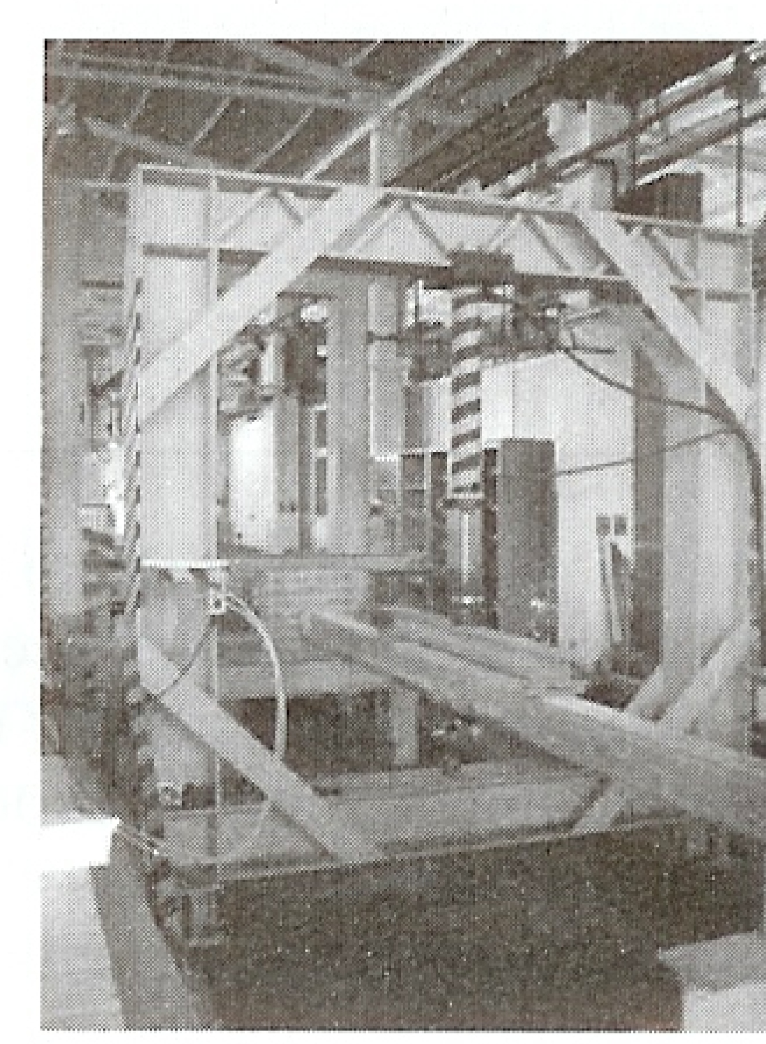




Figure 8,9,10 : Loading test on wall –floor connecting

After a 28-day curing time, each of the three samples prepared as illustrated above (Figs. 8,9,10) was subjected to loading test . The most meaningful results of each test are collected in the Tables 4 , 5 and 6.

The first loading test pointed out (Figs. 11,12) that the failure of concrete occurred at the top edge of the joist due to the reaching of the ultimate compressive strength of the material; failure corresponded to an ultimate failure moment Mu (577 daN * 1,40 m) of daNm 807,8 in the reacting section. The second test (Figs. 13,14,15) showed that the failure of concrete occurred at the top edge of the joist at the left joist-wall connection and at the same time allowed to remark the bending and initial extraction of the Φ 8 threaded bar.

Table 4 : Results of the first bending-shear tests on the chemical anchor with Φ 8 bar

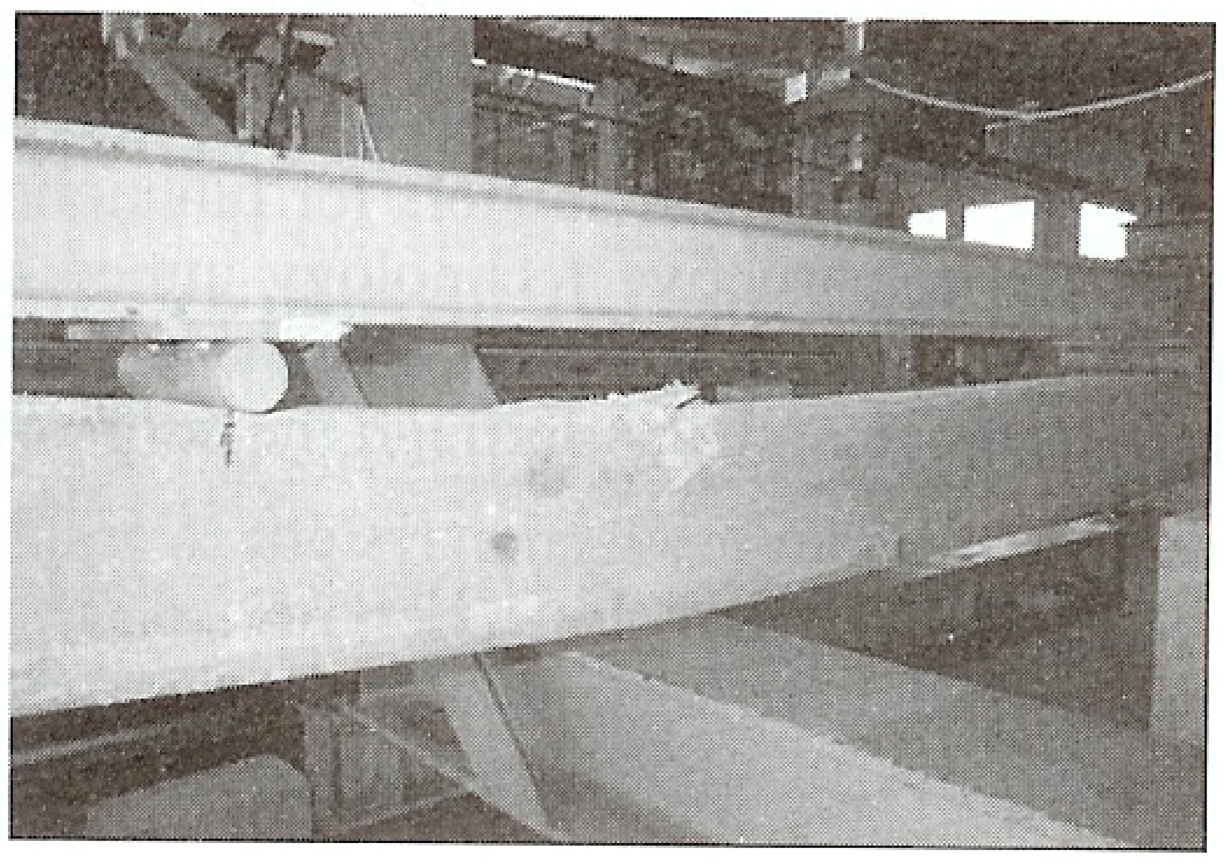
2P load at jack (daN)	P load on distributing device (daN)	Centesimal reading at midpoint (mm)	Midpoint deflection (mm)
0	0	4,96	0
100	50	6,49	1,53
200	100	9,33	4,37
300	150	13,20	8,24
400	200	17,80	12,84
600	300		Comparator removal
700	350		
1000	500		
1100	550		
1154	577	(a)	

Table 5 : Results of the second bending-shear tests on the chemical anchor with Φ 8 bar

2P load at jack (daN)	P load on distributing device (daN)	Centesimal reading at midpoint (mm)	Midpoint deflection (mm)
0	0	Not recorded	Not recorded
100	50		
200	100		
300	150		
400	200		
600	300		
700	350		
1000	500		
1094	547	(b)	

What arises from the first typology of anchoring system (resin + Φ 8 threaded bar) means that as far as the connection's ultimate behaviour, the prevailing effects remarked during the first test are of a bending nature, while the second test is characterized mostly by shearing effects.

The last loading test, differing from previous tests in the use of a Φ10 threaded bar in the beam-wall connection, mostly showed the formation of cracks due to shear/tensile stresses on the two masonry facings fixing the joist.



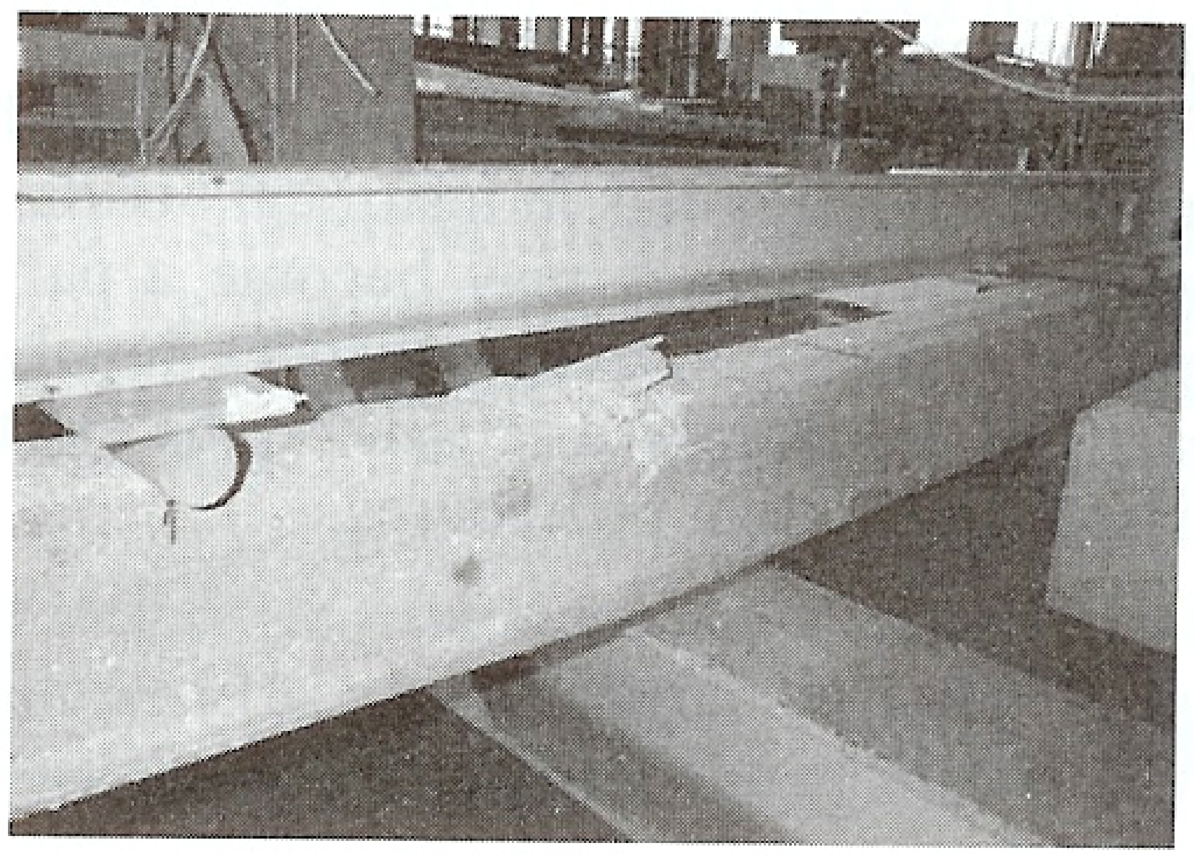


Figure 11, 12 : Concrete failure at the connection

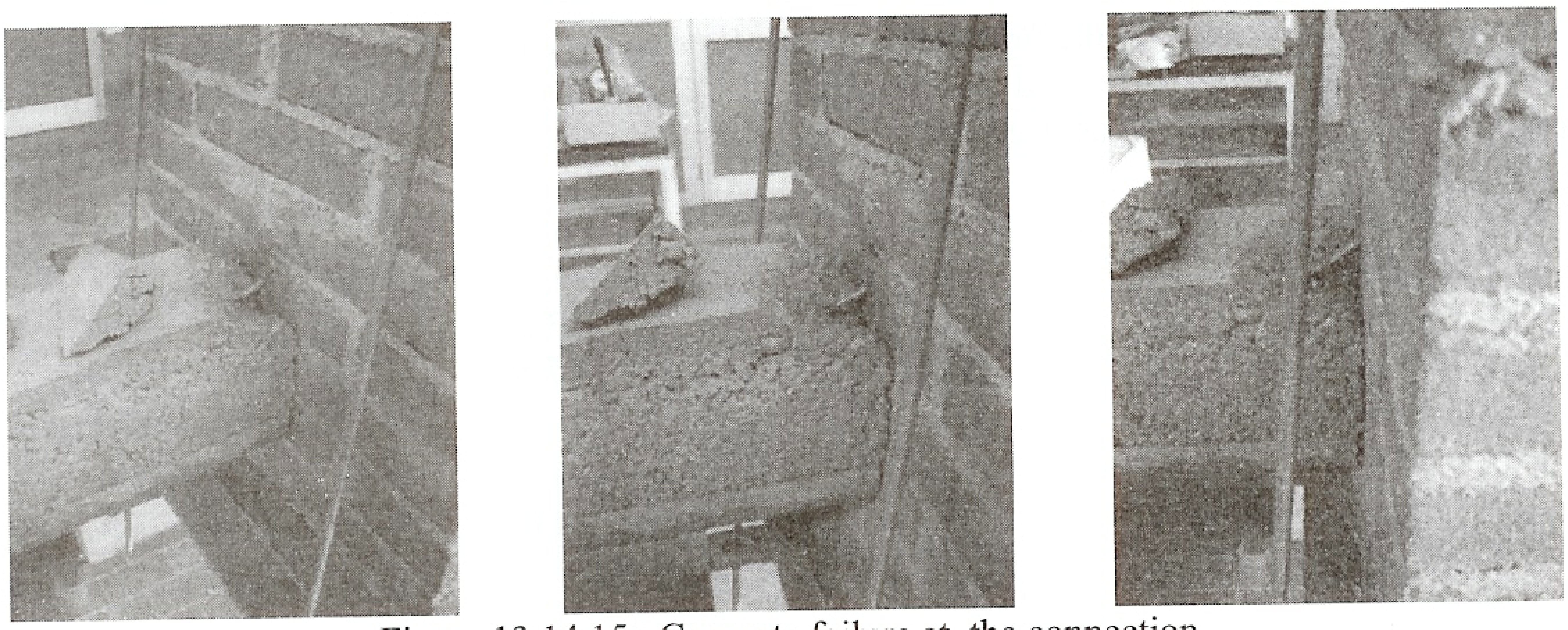


Figure 13,14,15 : Concrete failure at the connection

Table 6 : Results of the third bending-shear tests on the chemical anchor with Φ 10 bar

2P load at jack (daN)	P load on distributing device (daN)	Centesimal reading at midpoint (mm)	Midpoint deflection (mm)
0	0	3,21	0
100	50	4,60	1,39
200	100	6,35	3,14
300	150	9,15	5.94
400	200	12,18	8,91
600	300	22,20	18,99
700	350	27,90	24,69
1000	500		Comparator re-moval
1100	550		
1200	600		
1300	650		

5 CONCLUSIONS

This paper presents the experimental results obtained through a testing campaign carried out to asses the fitness for use of a chemical fixing system in expectation of the start of activities of EOTA on this type of technology and use of anchoring systems.

The results obtained have demonstrated that the system can be adopted to reconstruct and/or strengthen the deckings in historical buildings where the use of chemical anchors for functional re-adjustment purposes may become a particularly suitable constructive technology aimed at simplifying the operative sequences involved in the reconstruction activities thanks to low-impact and less intrusive actions on the existing building heritage and also through the adoption of simple assembling procedures.

REFERENCES

AA.VV, (1997), *Design of fastenings in concrete*, CEB, Lausanne (CH) .

AA.VV, (1997), *Guideline for European Technical Approval of metal anchors for use in concrete*, EOTA, Brussels.